Sustaining PICA for future NASA Robotic Science Missions including NF-4 and Discovery

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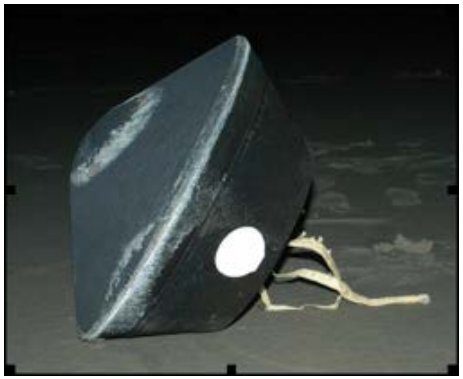
Outline

- **Background**
  - Heritage PICA
  - PICA Sustainability Challenge
  - Lyocell – an alternative precursor to rayon
  - PICA Manufacturing
- **Establishment of PICA-D as a Replacement for Heritage PICA**
  - Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing
  - PICA-D Property Testing
  - PICA-D Arc Jet Testing
- **CY18/19 work**
  - Establish PICA-D as a drop-in replacement for Heritage PICA
  - Establish the Expanded Capability (Extensibility) of PICA-D
  - PICA-D CY18/19 Schedule
- **Summary**
- **Acknowledgements**

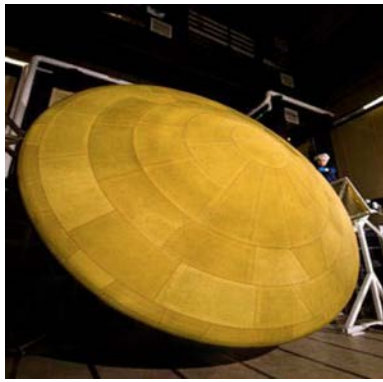
Background – PICA

State of the Art Low Density Carbon Phenolic Ablators

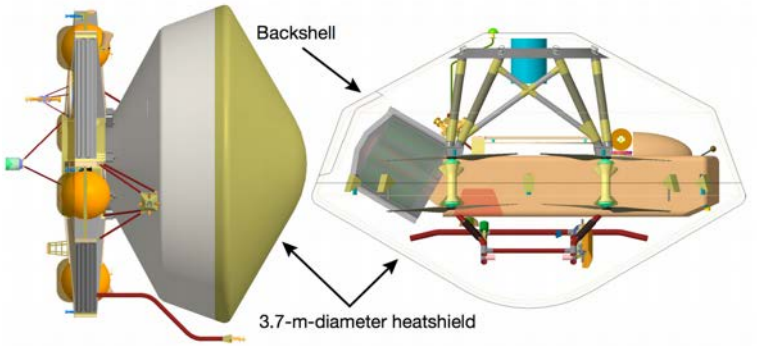
- **Phenolic Impregnated Carbon Ablator (PICA)**
  - first used as forebody single piece heatshield for Stardust
- **Low density coupled with efficient ablative capability at medium-high heat fluxes**
- **Since Stardust,**
  - PICA used on Mars Science Lab (MSL) in a tiled configuration,
  - OSIRIS-REx sample return capsule as a single piece
  - slated for Mars 2020
- **Based on successful mission use across destinations ranging from earth return to Mars, PICA has been proposed as the TPS option for numerous New Frontier and Discovery missions.**



Stardust forebody TPS. (~0.8m diameter)



MSL Heat Shield (4.5m diameter)



Dragonfly forebody TPS (~3.7 m diameter)
Currently NF – Phase A

Background - Sustainability

Challenges with PICA Sustainability

- In 2016 NASA learned that the heritage rayon used in PICA was ceasing production, leading to a flight-qualified PICA sustainability concern
  - The carbon fiber precursor for PICA has become obsolete twice since the material was developed and used on Stardust, so a secure source is essential to maintain PICA capabilities for future missions
- In FY16/17, NASA ARC was funded by the Planetary Science Division of the Science Mission Directorate to address PICA rayon sustainability
- Lyocell Based PICA (PICA-D) was manufactured and limited testing performed – initial results indicate Lyocell is a good candidate as a potential replacement for heritage rayon

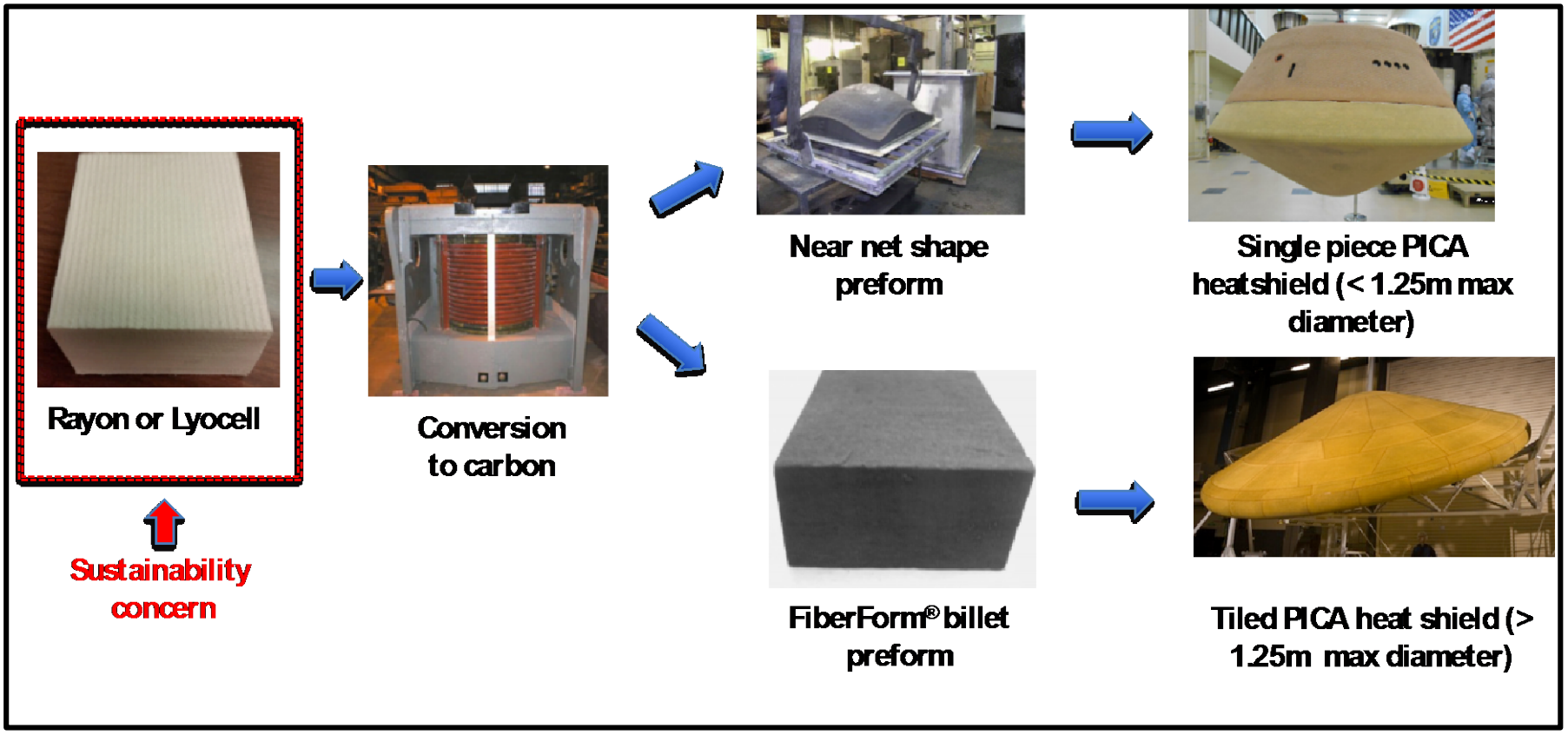
Lyocell – A Sustainable Precursor

- Traditional rayon manufactured from wood pulp involves many steps and the conversion of wood pulp into rayon or regenerated cellulose results in toxic byproducts
  - rayon manufacturing was discontinued and is no longer a viable process in the US and Europe
- Lyocell - solvent spinning technique is simpler and more environmentally sound
  - uses a non-toxic solvent chemical that is 99% recycled in the manufacturing process
- Lenzing – sister factories in US and UK able to provide the same Lyocell precursor – dual supply routes alleviate future sustainability concern

Refer to below links if interested in information on how fibers are made from wood pulp:
https://www.youtube.com/watch?v=tHdJGFv99fE
https://www.youtube.com/watch?v=14PZNgRoEUM

PICA Manufacturing Overview

Role of Rayon/Lyocell in PICA Manufacturing



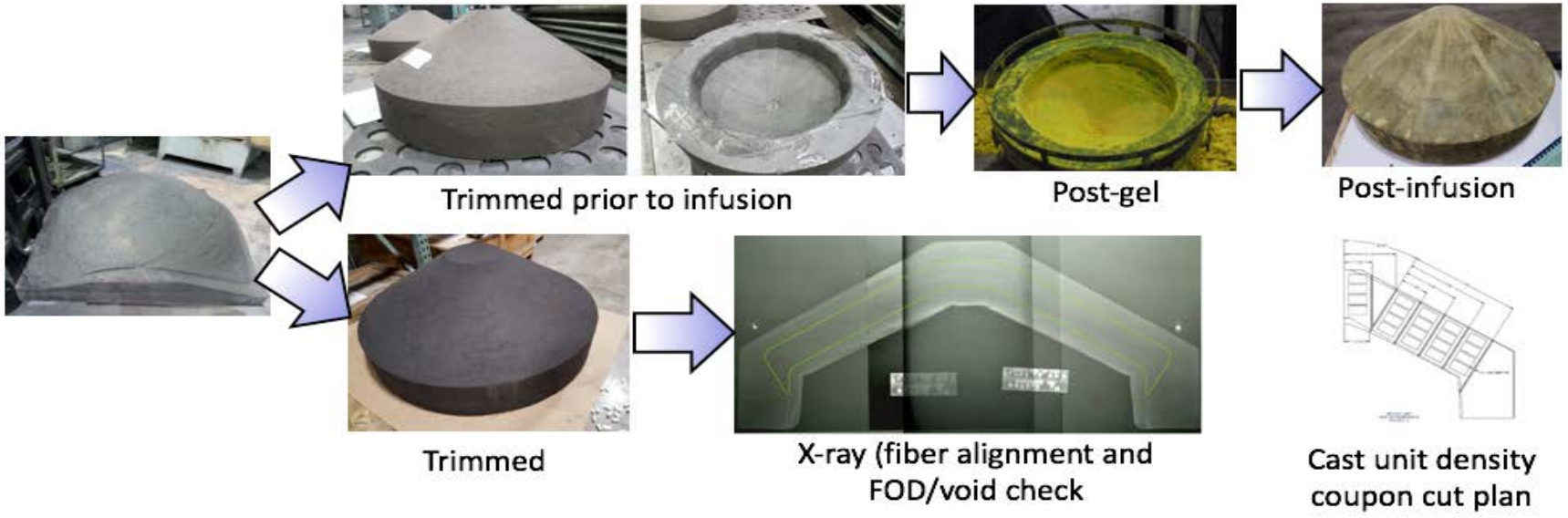
- Chopped, graphitized rayon or Lyocell - based carbon fiber slurry-cast into either block (billet) or single piece heatshield preforms
- Single piece cast heatshields have fiber oriented to optimize through-thickness thermal conductivity
- Lightweight phenolic sol-gel matrix is infiltrated into preform

Establishment of PICA-D as a Replacement for Heritage PICA

- **FY17 - SMD-PSD funded NASA Ames to manufacture & perform limited property/aerothermal characterization of Lyocell-based PICA (PICA-D)**
  - Fiber Processing, billet fabrication, single piece heatshield preform fabrication, conversion to PICA (billets and single piece preform)
  - PICA property testing and arc jet testing
- **FY17 task successfully completed - limited testing indicates PICA-D has the potential to be a drop-in replacement for heritage PICA**
- **FY18/FY19 - NASA Ames leading an effort to further characterize and extend the capability of PICA-D and establish Lyocell PICA as a drop-In replacement for heritage PICA**
  - Establishing PICA-D as a “drop in replacement” will allow missions to depend on and design with PICA-D without having to address further sustainability risks.
  - Establishing extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before.
    - Extended operational capability
    - Extended single piece heatshield manufacturing

Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing

- 9 FiberForm billets manufactured in FY17 to optimize process (Lyocell)
- Fabricated 3 net-shaped Fiberform heatshield blanks (OSIRIS REx scale) in FY17
  - Density targets in all 3 net cast blanks were achieved
- Process refinements and lessons learned have been documented
- Limited Non Destructive Evaluation (NDE) on the near net shape FiberForm unit to evaluate fiber alignment
- FY18/19 demonstrate repeatability and increase single piece net cast >1.2-m



PICA-D Property Testing

- **3 billets of PICA-D were manufactured to support testing**
  - Limited In-plane (IP) tension, through-thickness (TT) tension, and through thickness thermal conductivity at 100F and 350F were conducted and compared to heritage rayon PICA
- **Overall these results are in family with production rayon PICA – however additional testing is needed as only a few coupons were evaluated**
  - Limited property data had substantial scatter – detailed testing planned for FY18/19

Mechanical Property Comparison

	Density (g/cc)	Average Failure Stress (psi)
Average Lyocell PICA IP properties	0.28	246 *160 - 255 for rayon PICA*
Average Lyocell PICA TTT properties	0.28	44 *43 to 54 for rayon PICA*

Thermal Property Comparison

	Thermal Conductivity (BTU-in/hr-ft^2-^{o}F)	
	at 100°F	at 350°F
Average Lyocell PICA TTT properties	0.94	1.32
Rayon PICA TTT properties	1.0 – 1.5	1.5 – 2.1

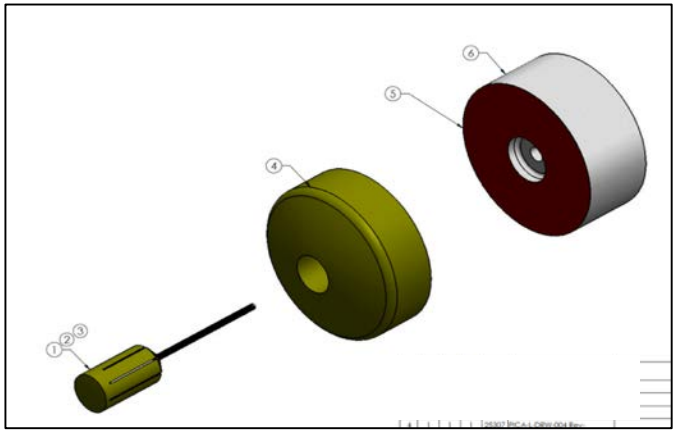
PICA-D Arc Jet Testing

- **Primary test objectives**
  - compare the thermal response and recession behavior of Lyocell derived PICA to rayon derived PICA
  - initial look at any performance differences or off-nominal behavior in PICA-D

- **3 conditions – testing completed in Oct 2017**
- **NF proposers provided guidance on target test conditions**

Arc Jet Test Matrix

Target Conditions	Objective	Comments
~ 220W/cm^2 and 0.08 atm (4" iso-q)	thermal response, recession	Instrumented coupon, calibration included **Testing in Oct 2017**
~ 400W/cm^2 and 0.3 atm (4" iso-q)	thermal response, recession	Instrumented coupon, **Testing complete Aug 2017**
~ 1550W/cm^2 and 1.3 atm (4" iso-q)	Failure mode evolution, thermal response, recession	Instrumented coupon, **Testing complete Aug 2017**

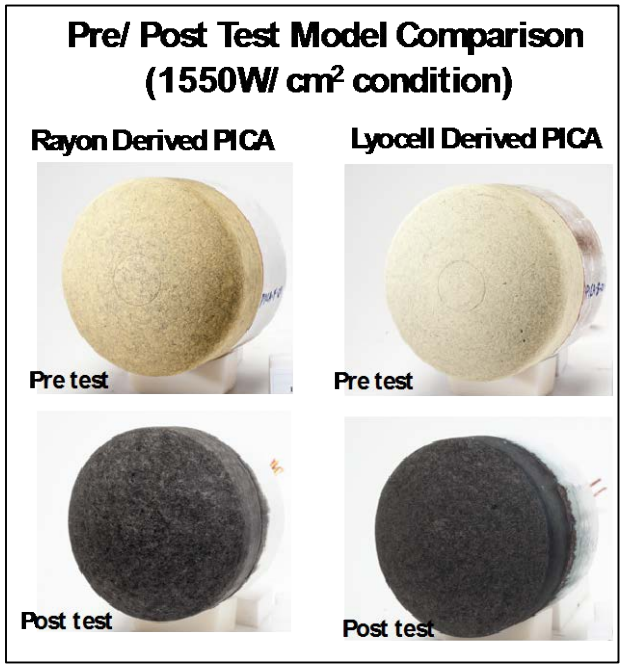


Coupon Geometry
- 4" iso-q coupons
- Each coupon instrumented with a plug containing 5 in-depth thermocouples consisting of 2 type-R and 3 type-K

PICA-D Arc Jet Testing - Results

Recession Comparison

Material	Average centerline recession (1550W/cm^2 and 1.3 atm)	Average centerline recession (400W/cm^2 and 0.3atm)	Average centerline recession (220W/cm^2 and 0.08atm)
Lyocell PICA	4.0mm	6.02mm	3.79mm
Rayon PICA	4.2mm	5.97mm	3.89mm



Limited # of models of each version of PICA tested at each condition

- Initial tests gives confidence that PICA-D will be a drop in replacement for heritage PICA
- Comparable recession and thermal response observed between PICA-D and heritage PICA
  - all coupons at a given condition had the same exposure time
- Run condition very relevant for NF proposers considering PICA as a forebody or backshell material
- Presence of dulling agent in PICA-D resulted in a slight decrease in char emissivity – future PICA-D precursor (Lyocell) will not use a dulling agent

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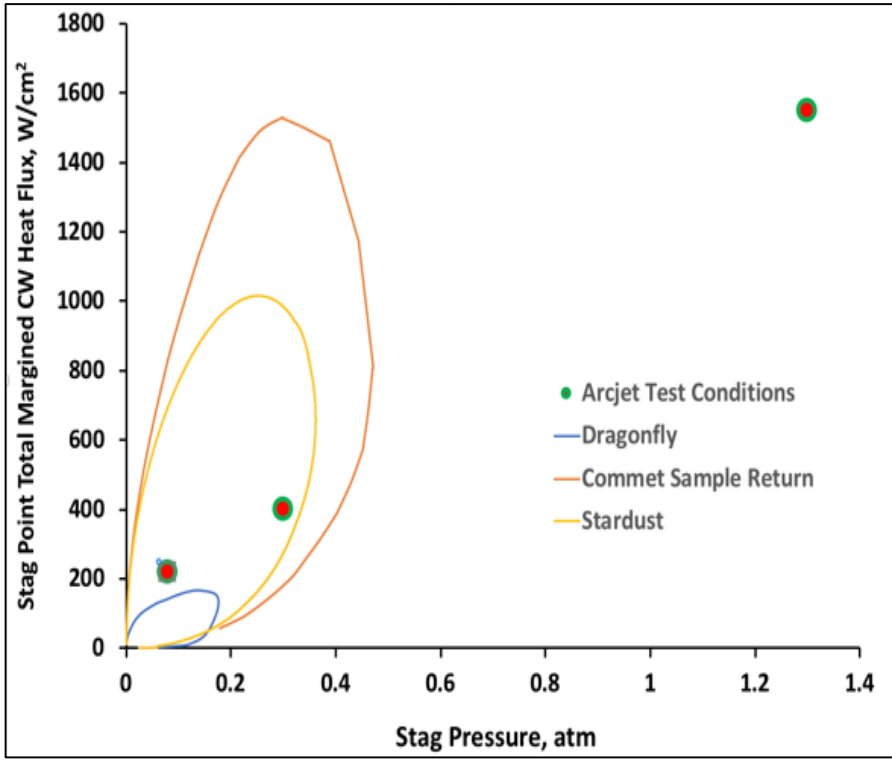
CY18/19 work - Establish PICA-D as a Drop-In Replacement for Heritage PICA

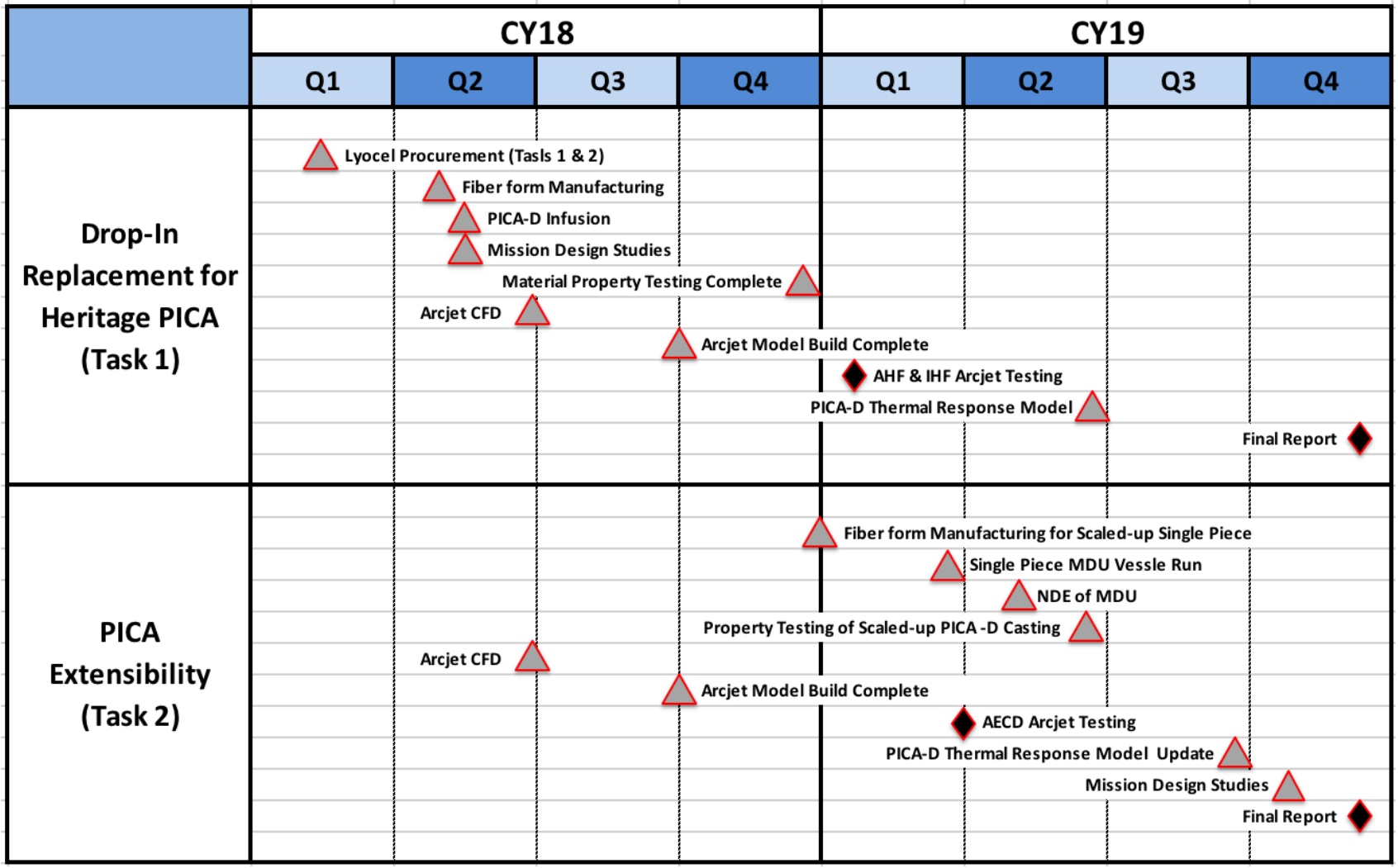
- **Develop comprehensive material property database**
  - Perform comprehensive material property testing (range of temperatures) for thermal and mechanical properties
- **Perform comprehensive arcjet test campaign**
  - Test at multiple conditions, including different material lots
  - Testing to include thermal response, instrumented stagnation and wedge shear coupons
- **Develop PICA-D thermal response model utilizing arcjet test data and new material**



CY18/19 work - Establish the Expanded Capability (Extensibility) of PICA-D

- **Demonstrate Manufacturing and Scale-Up of a Single Piece Heatshield at > 1.2m Diameter**
  - Perform comprehensive characterization and evaluation of single piece Fiberform casting
  - Characterize fiber alignment, mechanical properties and non-destructive evaluation (NDE)
- **Establish Expanded Design Space of PICA-D**
  - Perform arcjet testing at heat flux / pressure conditions beyond which PICA has previously been tested and / or flown (> 2000 W/cm^2, > 0.5 atm, TBD shear)
- **Increased single piece heatshield size - currently return speed limited to 12.9 km/s vs future potential of 13.5 – 14.5 km/s for entry bodies of diameter 1.5 X that of Stardust**

PICA-D FY18/19 Schedule



Summary

- **NASA ARC / FMI is working with the Planetary Science Division of the Science Mission Directorate to address PICA rayon sustainability concerns**
- **In FY16/17, Lyocell Based PICA (PICA-D) was manufactured and limited testing performed show it to be a good candidate replacement for heritage rayon**
- **Establishing PICA-D as a "drop in replacement" will allow missions to design with PICA-D without any competitive disadvantage over other competing proposals.**
- **Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speeds not considered before.**

Acknowledgement

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